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RF MEMS IMPROVEMENT PROGRAM

L-3 Government Services, Inc.

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This report has been reviewed by the Air Force Research Laboratory, Information Directorate, Public Affairs Office (IFOIPA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be releasable to the general public, including foreign nations.

AFRL-SN-RS-TR-2005-62 has been reviewed and is approved for publication

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The work performed under this task was in support of DARPA Special Projects Office (SPO) Micro Electro Mechanical Systems (MEMS) switch development efforts. The MEMS programs supported were developed and supervised by various DARPA/SPO program managers. During 2000 and early 2001, it became increasingly apparent that the RF MEMS switches and phase shifters being fabricated by all of the contractors working under various DARPA/SPO programs, that were directed toward using these components in various DoD system applications, suffered from various reliability problems which hampered their ability to function properly. In addition, no packages meeting DARPA's electrical and environmental system demands were available, at an acceptable cost, to house these devices.

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1. INTRODUCTION

The work performed under this task was in support of DARPA Special Projects Office (SPO) Micro Electro Mechanical Systems (MEMS) switch development efforts. During the majority of the period of performance, these MEMS efforts were under the direction of Dr. Larry Corey of DARPA/SPO. Near the conclusion of the effort, Dr. Larry Corey ended his tenure at DARPA and responsibility for the programs was transferred to Dr. Clark T-C. Nyugen of DARPA/MTO.

The MEMS programs supported under this subcontract were instituted as a result of predecessor programs that were developed and supervised by various DARPA/SPO program managers including Dr. John K. Smith, Col. Edward Gjermundsen and Dr. Larry Corey. During 2000 and early 2001, it became increasingly apparent that the RF MEMS switches and phase shifters being fabricated by all of the contractors working under various DARPA/SPO programs, that were directed toward using these components in various DoD system applications, suffered from various reliability problems which hampered their ability to function properly. In addition, no packages meeting DARPA's electrical and environmental system demands were available, at an acceptable cost, to house these devices. The lack of appropriate packages contributed to the reliability problems because the presence of water vapor (humidity) resulted in a principal reliability problem--stiction. Stiction is defined as the inability for a switch position to be changed from closed to open or occasionally from open to closed because the moving switch parts stick to one another. In addition, unpackaged devices are exposed to a variety of contaminants and particles, any of which can degrade their performance.

2. MEMS RELIABILITY ASSESSMENT TEAM

In February 2001, a MEMS Reliability Assessment Team was assembled. Its mission was to assess the status of RF MEMS components being fabricated by the four DARPA/SPO contractors developing MEMS switches and phase shifters at that time, examine reliability problems being encountered, and determine whether or not the requisite phase shifters would be available, in sufficient quantities and with reliable operating characteristics, at a time which would allow their use in the Low Cost Cruise Missile Defense (LCCMD) program. An additional requirement was that the phase shifters and their required packages could be produced at an acceptably low cost. When it became clear that these components and packages would not meet the necessary reliability and packaging requirements, a new program was developed by Dr. Corey entitled the "RF MEMS Improvement Program (RFMIP)." This on-going program is focused upon developing highly reliable RF MEMS switches that can operate at frequencies up to 35 GHz and suitable packages for housing them that will cost $5 or less in reasonably large quantities. A summary of the objectives of this on-going program is as follows:

DARPA is interested in developing advanced technologies, designs, fabrication techniques, materials, and packaging concepts that can be applied to the large scale manufacture of RF Micro-Electro-Mechanical Switches (MEMS) and related components. The purpose of this program is to explore the feasibility of fabricating low cost, highly reliable MEMS devices and components for future defense systems. The resultant devices should have performance that exceeds that afforded by competitive solutions. Goals for the MEMS switches include:

- Operational lifetime ≥ 100B cycles with dc bias voltage and RF power applied.
- Operation at X-band, Ku-band and/or Ka-band.

- Packaged Insertion loss: < 0.3 db at X-Band; < 0.5dB at Ku-Band; < 0.7 dB at Ka-Band; isolation > 20db; return loss < 15db.

- RF Power handling > 1 watt peak pulsed at 10 KHz to 100 KHz rate with 25% duty, cold switching of MEM switch.

- Shelf life > 10 years.

- Hold down time > 1 minute (hold down time is the longest period that a switch will be required to remain in a given position).

- Switching Speed: < 50μ seconds.

- Operating environment –40 deg C to 60 deg C; 80% humidity; 9 year Low Earth Orbit (LEO) life.

- Cost of packaged device < $5.

- Actuation Power consumption < 1mw.

The RFMIP program is a two phase effort. Phase I includes tasks to develop and demonstrate the tools, methodologies and capabilities leading to the ability to produce required RF MEMS components, at an affordable cost. Frequently during the course of Phase I, MEMS switches and test structures are being fabricated to allow assessment of the value of design changes, processing changes, models developed, simulations performed and packaging approaches. The models, simulations, and improvements in fabrication approaches and packaging tasks undertaken during this phase are expected to result in significant improvements in the performance, yield and reliability of the RF MEMS devices and components developed. Among these many fabrication and test cycles, there will be two 'benchmark' fabrication lots. Performance and reliability of fabricated MEMS devices have been "benchmarked" at 9 months ARC and 18 months ARC to determine whether the tasks being executed are resulting in the desired performance and reliability enhancements. Each benchmarking activity has consisted of a run of three lots of RF MEMS wafers (six or more wafers/lot). From these lots, a sufficient number of devices were selected randomly (i.e., from different lots, different wafers and different positions on the wafers) to constitute a sample size appropriate for statistical analysis which will demonstrate that the goals for performance, yield, reliability and lifetime are improving.

Three contractors, Northrop Grumman Electronic Systems (NGES, Baltimore, MD), Northrop Grumman Space Technologies (NGST formerly TRW, Redondo Beach, CA) and Radant MEMS, Inc. (Stow, MA) were selected during early 2002 to participate in the RFMIP program. Of these, only Radant MEMS, Inc. is currently under contract. It has met most of the objectives of the program.

3. PRINCIPAL TASKS PERFORMED IN CALENDAR YEAR 2002

Proposals for RFMIP program were reviewed. Participated in the proposal evaluation meetings.

Briefed Dr. Corey of DARPA on the (related) DARPA/MTO Intelligent RF Front Ends (IRFFE) program and discussed the intended application of RF MEMS in IRFFE subsystems.

Participated in various pre-contract discussions with Dr. Corey, Ms. Jacqueline Toussaint-Barker of AFRL and other members of the DoD RFMIP team.

Reviewed and commented on revised statements of work submitted by the selected RFMIP contractors, as requested by Dr. Corey and Ms. Toussaint-Barker.

Reviewed and commented on the draft RFMIP DARPA Program Approval Document.

Assisted in preparation of presentation material for the RFMIP/RECAP conference conducted under the direction of Dr. Corey during August 2002.

Attended and participated in the RFMIP/RECAP conference.

Prepared and forwarded to Dr. Corey a summary of the "Government Only" session at the MEMS/RECAP conference and a summary of Dr. Gabriel Rebeiz's presentation at the conference.

Prepared and submitted a report summarizing the overall conference.

Attended and participated in the Radant RFMIP kickoff meeting.

Prepared presentation charts providing rationale for DARPA/SPO conducting the RFMIP program, at the request of Dr. Corey.

Attended and participated in the NGES and NGST (formerly TRW) RFMIP kickoff meetings.

Reviewed and suggested additions to the draft strawman RF MEMS test plan prepared by Lt. Col. William Cowan of AFRL. Continued work on the development of this test plan with other members of the DoD RFMIP team.

Assisted in the preparation of an updated RFMIP briefing, prepared by Dr. Corey for presentation to Dr. Amy Alving, Director of DARPA/SPO.

As requested by Dr. Corey, attended and participated in a Raytheon meeting to discuss Raytheon's use of MEMS in electronically scanned arrays (AESAs).

Attended Northrop Grumman and Radant RFMIP program reviews; prepared and submitted summary reports of these reviews.

Reviewed and commented upon RFMIP monthly progress reports submitted by NGES.

4. PRINCIPAL TASKS PERFORMED IN CALENDAR YEAR 2003

Throughout the year, reviewed and commented upon RFMIP status reports submitted by NGES, NGST and Radant MEMS, Inc.

Attended and participated in several RFMIP program reviews at NGES, NGST and Radant MEMS, Inc. contractor sites and at locations within Arlington, VA.

Prepared summary reports, comments and recommendations about information presented at various RFMIP contract reviews.

Attended and participated in a review of the Lockheed Martin/GE MEMTenna program, as requested by Dr. Corey.

Prepared draft charts on the status of the RFMIP program for use by Dr. Corey in preparation for his presentation of the program to the Director of DARPA. Worked with Dr. Corey and other members of the DoD RFMIP team in the development of presentation material.

Prepared draft presentation on RFMIP contractors' modeling activities for use by Dr. Corey in briefing Dr. Alving and Dr. Tether (Director of DARPA).

Reviewed test data from NGES RFMIP program.

Met with NGES personnel, Dr. Corey, Ms. Toussaint-Barker and others on the DoD RFMIP team to discuss the proposed rescope of the NGES RFMIP program.

Reviewed and commented upon the revised statement of work, schedule and cost plan submitted by NGES.

As requested by Dr. Corey, read and commented upon a University of Colorado report on ALD coatings for reliable RF MEMS switches.

Discussed suggested revisions to the NGES RF MIP test plan with Ms. Toussaint-Barker, as requested.

Developed idea for new "seedling" program, as requested by Dr. Corey and forwarded it to him for his consideration and comment.

5. PRINCIPAL TASKS PERFORMED IN CALENDAR YEAR 2004

Reviewed and commented upon RFMIP status reports submitted by NGES and Radant MEMS, Inc.

Attended and participated in NGST and Radant RFMIP program reviews at the contractors' sites and at locations within Arlington, VA.

Prepared reports on NGES and Radant RFMIP program reviews and forwarded them to Dr. Corey.

Reviewed and commented upon reliability test results for Radant RF MEMS switches provided by Mr. Dan Judy of ARL.

As requested by Ms. Toussaint-Barker, reviewed Radant MEMS Inc. Benchmark 2 test plan and forwarded comments about it to Dr. Corey and Ms. Toussaint-Barker.

Provided recommendations concerning reliability testing of Radant RF MEMS devices.

Reviewed additional reliability test results provided by Dr. Harvey Newman of NRL and Dr. Jack Ebel of AFRL.

Reviewed information on approaches to statistical analysis of Northrop Grumman switch lifetimes.

Participated in the DoD Wide MEMS and DARPA MEMS PI meetings in Seattle, WA, as requested by Dr. T.-C. Nyugen.

Attended and participated in the MEMtronics HERMIT MEMS review, as requested by Dr. Nyugen.

Reviewed charts from the MEMtronics review and forwarded suggestions and comments about the program to Dr. Nyugen.

As requested by Dr. Nguyen, provided suggestions about possible DoD applications of RF MEMS switches.

Contacted industry representatives at NGST and Raytheon to determine their plans for using RF MEMS switches in DoD applications. Forwarded the information obtained from them to Dr. Nyugen.